TECHNICAL GUIDANCE FOR TRANSIENT VOLTAGE SURGE SUPPRESSORS

Michael McInerney, P.E.
CECER-FL-P
217-373-6759

Thomas Luu
CECPW-EE
703-806-5163

INTRODUCTION

Sensitive electronic equipment such as computers and telecommunications equipment, audio/video equipment, electronic ballasts and variable speed drives, can be damaged by transient overvoltages on the electrical power system. These transients are generally caused by switching of electrical power circuits or by lightning. Since the occurrence of damaging transient overvoltages is unpredictable, disconnection from the electrical supply in order to avoid damage is not always possible. Therefore, critical and expensive electronic equipment must be protected from transient overvoltages with transient voltage surge suppressors (TVSS).

There are three standards which, when used properly, can be used to select a TVSS unit: IEEE C62.41-1991[1], NEMA LS1-1992[2], and UL 1449[3]. IEEE C62.41 provides guidance on the transient environment; UL 1449 addresses safety issues; and NEMA LS1 recommends, in general terms, TVSS specifications. Although UL 1449 includes performance tests, it is primarily a safety standard. It is not appropriate, therefore, to qualify a TVSS unit based solely on the UL 1449 listing information. TVSS selection should also consider additional performance and rating information provided by an independent source or the manufacturer.

This paper addresses TVSS units for low voltage ac power systems (600 Volts and less) located within the United States. This covers most facility installations from the service entrance to the end-user (120 Volt outlet). The following special cases are not included in this guide:

- hospital and hazardous material storage;
- surge suppression of telephone and data lines;
- EMI/RFI filters (oftentimes included with TVSS units);
- Electrical disturbances caused be High-Altitude ElectroMagnetic Pulse (HEMP).

DEFINITIONS

Some confusion is associated with the use of the terms arrester, protector, suppressor, impulse, surge and transient. A brief explanation of these terms, as used in this paper, will be given.

From an electrical power perspective impulses are short duration events where the voltage (or current) increases above (in an absolute value sense) its nominal value for a fraction of a cycle, whereas surges are longer duration events. Transients, therefore, are high voltage and/or current impulse events. However, since surge has become the common term for what is actually an impulse event, the term surge will be used in this document when referring to transient handling devices.

In this paper surge suppression component or surge suppressor will be used when referring to an individual surge limiting component, or surge arrester, such as a MOV or diode; Asurge protector@ or Atransient voltage surge suppressor@ will be used when referring to a surge limiting unit, which will generally be composed of a number of surge arresters.

Line-to-line will be abbreviated as L-L, line-to-neutral as L-N, line-to-ground as L-G, and neutral-to-ground as N-G.

TVSS TECHNOLOGIES

SURGE SUPPRESSION COMPONENTS

There are three main surge suppressor technologies used in transient voltage surge suppressors: gas tube, varistor, and semiconductor. A fourth technology, reactance, by itself provides limited impulse suppression, however it plays a large role in implementing suppression technologies. Suppression technologies rely on nonlinearities in the suppressor voltage-current (V-I) behavior to conduct current only after a threshold voltage is reached. Reactance devices rely on inductance and capacitance to store or divert electrical energy.

Performance Characteristics

Because the basic physics of each surge suppressor technology is different, a one-to-one comparison of these devices is not possible. However, there is some similarity in performance characteristics. The most important measured performance characteristics for these technologies are listed in Table l and are grouped by similarities. Table 1 does not list all the device performance characteristics, just the most relevant ones.

TABLE 1. PERFORMANCE CHARACTERISTICS OF SURGE SUPPRESSOR TECHNOLOGIES.

Gas Tubes	Varistors	Semiconductor Devices
DC Breakdown Voltage	Rated DC Voltage	Rated Stand-Off Voltage
	Rated RMS Voltage	Rated Working RMS Voltage
Impulse Breakdown Voltage	Clamping Voltage	Clamping Voltage
Maximum Single Impulse Discharge Current	Rated Peak Single Pulse Transient Current	Rated Peak Single Surge Transient Current
		Rated Peak Impulse Current
	DC Standby Current	Stand-By Current
Impulse Life	Lifetime Rated Pulse Currents	Lifetime Rated Pulse Currents

The most significant characteristics for ac power applications are rated rms voltage, clamping voltage, and peak single pulse current.

The rated rms voltage of the suppressor is the maximum continuous sinusoidal rms voltage which may be applied over the standard operating temperature range without causing the suppressor to fail. Gas tubes and varistors are bi-directional (i.e. they have a symmetrical V-I curve) while semiconductor devices can be either uni- or bi-directional. The rms voltage rating applies only to bi-directional devices. The gas tube does not have a rated rms voltage, however it does have a rated dc breakdown

voltage. Since for a sinusoidal function 0, the rated rms voltage of the gas tube can be estimated. (The breakdown voltage is the point where the suppressor first begins to conduct. The gas tube is not fully conducting at this point, it is in the glow mode. To enter the arc mode, where the voltage across the tube is typically 20 Volts, the suppressor must begin conducting about 5 Amps. The dc breakdown voltage of the gas tube is measured with a waveform having a rate-of-rise less than 1000 V/s).

The clamping voltage for varistors and semiconductor devices is the peak voltage measured across the suppressor while conducting a specified peak pulse current. A similar condition for gas tubes is the impulse breakdown voltage. Because the breakdown voltage of a gas suppressor increases as the applied voltage rate-of-rise increases, a separate performance measurement is made for fast rate-of-rise impulses (rate-of-rise 100 V/ s to 10 kV/ s).

The rated peak single pulse current is the maximum value of peak impulse current which may be applied for a single impulse without causing device failure.

Recommended waveforms for conducting the above performance ratings are the 8/20 s and the 10/1000 s waveshapes.[1] Caution should be used when comparing ratings taken using different waveforms. Although the rise times of these waveforms are similar, for a given peak current the longer duration of the 10/1000 s waveshape will deliver more energy into the device. This will affect the rated peak single pulse current test, since dissipation of too much energy within the device leads to failure. The 10/1000 s waveshape is a harder test.

Gas Tubes

These devices are small sealed spark gaps containing rare gases (e.g. argon and neon). When the voltage rises past the suppressor breakdown voltage, a gas breakdown is initiated. Unfortunately this can take a little time to start and then develop into a low impedance. As a consequence, fast rising pulses will initiate breakdown at a higher voltage than more slowly rising pulses. The delays in breakdown mean that some part of a surge can pass this type of suppressor. Once the gap has broken down the gas discharge goes into either a glow mode ($I < 5$ Amps) or at higher currents an arc mode. In the arc mode the clamping voltage is about 20 Volts whereas in the glow mode it is 70 - 150 Volts. This characteristic can present problems in ac power applications because the supply can provide enough current to keep the spark gap conducting. Protection levels can vary from 75 to 10,000 Volts. Gas suppressors have the highest surge handling capability ($I > 20{,}000$ Amps) with response times down to 1 ns.

Varistors

Although metal oxide varistors (MOV) are oftentimes thought of as semiconductors, they are actually non-linear resistive devices made of sintered blocks of zinc oxide or lead oxide usually mixed with some other metallic oxides. Since the MOV is basically a resistive device the clamping voltage is current dependent. The larger the current the greater the clamping voltage. For example, the clamping voltage of an 18 Volt, 3 Joule MOV can vary from the rated breakdown voltage of 18 Volts (at 1mA) to 31 Volts at 1 Amp to 48 Volts at 80 Amps. MOVs are available in a wide range of operating values from 10 Volts at 100 Amps to 4,700 Volts at 70,000 Amps. MOVs have a large capacitance (100-4000 pF depending on rating) and a response time less than 30 ns. Unlike gas tubes, MOVs have a small leakage current. Normally this

---

[1] These waveshapes approximate double exponential waveforms with rise times of 8 and 10 µs, respectively, and pulse durations of 20 and 1000 µs, respectively. See IEEE C62.41 for exact definitions.

current is less than 0.1 mA but rises as the MOV deteriorates. MOVs of similar voltage rating can be combined (stacked) in either parallel or series. Stacking increases peak current-handling capability and peak energy dissipation.

Another type of varistor is the silicon carbide varistor. Its V-I characteristic is such that it does not have a tight clamping voltage. For practical low voltage use it must be combined in series with a gas tube, which may result in a relatively large let through voltage. This makes silicon carbide suppressors unsuitable as the sole device for protecting electronic systems.

Semiconductor Devices

The original semiconductor type of surge suppressor is the avalanche diode. These devices have an accurately defined breakdown voltage and operate as a voltage clamp at that voltage. They are limited to voltage protection levels between 2 and 400 Volts and pulsed currents between 1000 and 20 Amps for the respective voltage values. Avalanche diodes have fast switching speeds and large capacitance (500-2000 pF).

Semiconductor devices have been developed specifically for surge suppression. One line of surge suppressors is fabricated using a large junction area, which is a basic requirement for a surge suppressor, and can handle up to 3000 Amps for small pulses. Another type consists of an SCR-type thyristor whose gate region contains a special diffused section that acts as an avalanche diode. The combination of the fast response time of the avalanche diode and the high current handling capability of the thyristor yield a surge suppressor.

In voltage clamping applications semiconductor devices are operated in the reverse bias direction and are therefore uni-directional. They are configured as bi-directional (two devices in series, of opposing polarities, in one package) for transient applications. Semiconductor devices can be connected in series or parallel to increase power dissipation.

Semiconductor devices are typically rated in peak pulse power dissipation, 0, where 0 is the Peak Pulse Power, 0 is the Maximum Clamping Voltage, and 0 is the Peak Pulse Current. Since device breakdown is energy dependent, as pulse width decreases, peak pulse power handling increases. For example, a device with 01500 Watts for a 10/1000 s pulse has 013,000 Watts for a 8/20 s pulse.

TVSS STANDARDS

There are several industry standards concerning surge arresters and surge suppressors. The largest collection of surge protection standards is published by the IEEE. The IEEE C62 series contains 21 standards related to surge protection. Other organizations with TVSS standards are NEMA and UL. The three most important standards related to surge suppressor selection will be described in this section.

IEEE C62.41-1991

IEEE C62.41-1991 AIEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits@ presents several waveforms which characterize impulses on power circuits. The development of these representative waveforms was based on a combination of data from published surveys, anecdotes, and observed failure rates. Characteristics used to develop these waveforms were amplitude, rate of occurrence, surge duration, ringing frequency, rate of voltage change, energy delivery capability, and the effects of loading conditions. Five waveforms are presented, two are recommended as standard test waveforms and three are recommended for additional tests. The standard impulse conditions are represented by two voltage-current waveforms with amplitude and available energy dependent upon the pertinent location within the power system or distance from the surge source.

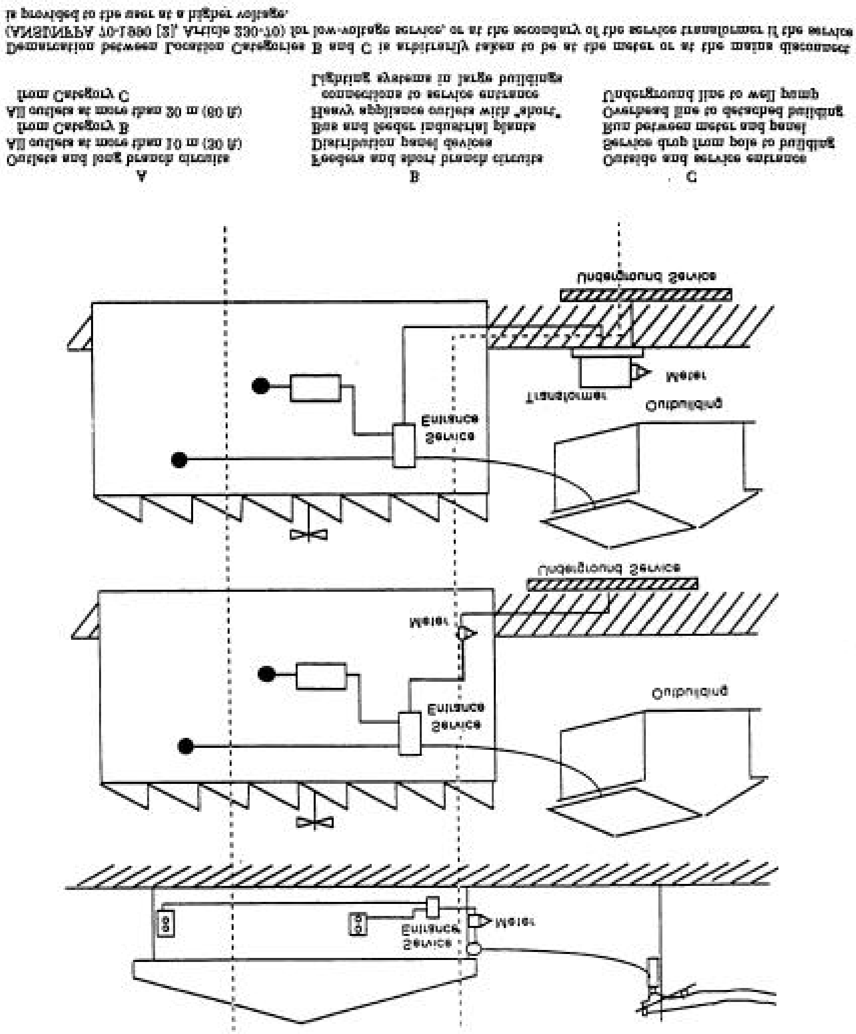
Locations are divided into three categories. Each category is then subdivided by exposure level. The locations are:

- Category A: Long branch circuits, receptacles (indoor).
- Category B: Major feeders, short branch circuits, service panel (indoor).
- Category C: Outdoor overhead lines, service entrance.

Figure 1 graphically illustrates these divisions.

The three exposure levels are:

- Low Exposure: Systems in geographical areas known for low lightning activity and with little load-switching activity.
- Medium Exposure: Systems in geographical areas known for medium to high lightning activity, or with significant switching transients, or both.
- High Exposure: Those rare installations that have greater surge exposure than those defined by Low Exposure and Medium Exposure.



0

FIGURE 1. ILLUSTRATION OF SURGE LOCATION DIVISION BY CATEGORY (from IEEE C62.41-1991, reprinted with permission).

The recommended standard waveforms are the 100 kHz Ring Wave[2] and the 1.2/50 μs-8/20 μs Combination Wave[3]. Peak voltages and currents for these waveforms are given in this standard for each category and exposure level.

UL 1449

[2] This waveshape approximates an exponentially decaying sine wave with a fast rise time.

[3] The Combination Wave is generated using a generator calibrated to have an open circuit voltage waveform of 1.2/50 μs and a short circuit current waveform of 8/20 μs.

UL 1449 ATransient Voltage Surge Suppressors@ is currently the only standard in the United States to address performance of TVSSs. Although this standard addresses mainly the safety aspects of TVSSs, it does contain some performance specifications: measured limiting voltage and surge current. The waveforms and waveform parameters used for these tests are based on IEEE C62.41-1991.

UL 1449 divides TVSS units into three types:

Cord-connected - Any TVSS provided with a power-supply cord terminating in an attachment plug for connection of the device to a receptacle in the AC power circuit.
Direct plug-in - Any TVSS incorporating integral blades for direct insertion into a standard wall receptacle.
Permanently connected - Any TVSS provided with terminals or leads for field connection to wiring systems in accordance with the National Electrical Code, ANSI/NFPA-70. This includes receptacle type TVSS intended for installation in outlet boxes.

The peak voltages and currents used in the surge tests are smaller for the cord-connected and direct plug-in types than for the permanently connected type.

The measured limiting voltage test is performed on three previously untested units which are representative of the manufacturers specifications. Each of the units is subjected to impulse surges using the combination 1.2/50 s, 8/20 s voltage/current waveform with 0 and 0. All modes of protection for which the unit is rated are tested (e.g. L-L, L-N, N-G, L-G).

Following the limiting voltage test the units are subjected to impulse surges using the combination 1.2/50 s, 8/20 s voltage/current waveform with 0. Permanently connected units have an 0 while the cord-connected and direct plug-in units use a lower value of 0. This is the duty cycle test.

After the duty cycle test, the units are again subjected to the measurement of limiting voltage. The resulting measured limiting voltage must not deviate more than 10% from the original values and must not exceed the marked suppressed voltage rating by more than 10%.

The average of the measured limiting voltages, new and after the duty cycle test, must not exceed the manufacturers marked suppressed voltage rating. The suppressed voltage rating is assigned based on the measurements of limiting voltage. For limiting voltages less than 330 Volts, the suppressed voltage rating is 330 Volts. For limiting voltages between 330 and 1000, the suppressed voltage rating is assigned by rounding up to the nearest 100.

Three previously untested units are used for the surge current test. Each one is subjected to two impulses of the combination 1.2/50 s, 8/20 s voltage/current waveform. Permanently connected units use   0 and   0, nearly equivalent to category C3 of IEEE C62.41, the worst environment specified in that standard, while cord-connected and direct plug-in units use the lower levels of   0 and   0, equivalent to category B3 of IEEE C62.41, the worst environment for the facility interior environment. All modes of protection for which the unit is rated are tested (e.g. L-L, L-N, N-G, L-G).

NEMA LS1-1992

NEMA LS1-1992 ALow Voltage Surge Protective Devices@ was developed by the National Electrical Manufacturers Association to serve primarily as a guide for manufacturers and others associated with the low voltage surge protective device community to develop uniform specifications, in terms of valid, understandable physical parameters. Specification parameters, their definitions and test and evaluation procedures are given in the body of this standard.

TVSS SELECTION GUIDANCE

IEEE C62.41 and UL 1449 form a basis for selecting TVSS units. IEEE C62.41 provides guidance, in the form of standard test waveforms, for evaluating the electrical performance of TVSS units. These waveforms are based on actual and anecdotal data of surge occurrences in facility ac power systems. TVSS electrical performance evaluations using these standard waveforms offer some assurance that the TVSS can function adequately as a surge suppressor in the selected electrical environment. UL 1449 contains several performance tests, all based on the IEEE C62.41 standard waveforms, which can be used as performance evaluations.

UL 1449 states that a TVSS shall be plainly and permanently marked with the name of the manufacturer, a distinctive catalog number, the electrical rating, suppressed voltage ratings, the date of manufacture, and the word ATransient Voltage Surge Suppressor@ or ATVSS@.

The most important considerations in the selection of a TVSS unit are the rated nominal line voltage, the surge current capability and the clamping voltage. These three specifications are available from the UL 1449 rating.

The UL 1449 electrical rating includes nominal operating voltage and maximum current (for a series TVSS unit).

Suppressed voltage ratings are listed for each protected combination of leads or terminals (e.g. L-L, L-N, L-G, N-G). The suppressed voltage rating is assigned based on the measured limiting voltage (clamping voltage).

However, a UL 1449 rating does not guarantee superior performance. Additional information is necessary to fully evaluate TVSS performance.

Another consideration in evaluating performance ratings is that these ratings are made with a few typical units. Because of tolerance on components, which could be as high as 10%, actual performance may differ.

FACILITY EXTERIOR AND SERVICE ENTRANCE TVSS

Circuit Description

A TVSS unit for IEEE C62.41 Category C use, building exterior and service entrance, will be parallel connected and will contain MOVs as the primary surge suppression component. High energy MOVs (disc size   40 mm) are certain to handle the peak pulse currents possible at these locations, and therefore last longer. (MOV deterioration is manifested in a rise in both clamping voltage and leakage current.)

Silicon carbide varistors should not be used as the sole suppression component if sensitive electrical or electronic loads are being protected. Practical use in low voltage applications results in a relatively high let-through voltage, therefore they must be followed with a Atight@ V-I characteristic device, such as an MOV.

Diagnostic indicators, such as LEDs, which show suppressor condition are recommended. As a minimum, a good or failed MOV condition should be indicated. More sophisticated units monitor MOV deterioration and count surges. Redundant protectors provide continuous protection if one should fail. Plug-in modules make replacement of a failed suppression component easy.

Nominal Line Voltage

The rated nominal line voltage of the TVSS unit must be equal to or greater than the system line voltages for the protected modes (e.g. L-L and L-N). This information is available from the UL label and the manufacturer.

Maximum Continuous Line Current

This rating applies to TVSS units which are installed in series with the line and/or neutral conductors. Since exterior and service entrance units will be parallel connected this rating is not relevant.

Maximum Continuous Operating Voltage

The maximum continuous operating voltage must be at least 10% above the nominal line voltage. A UL 1449 rating assures that the unit can operate at 110% of the nominal line voltage. If continuous operation at voltages grater than 110% of the nominal line voltage is required then it is necessary to check the manufacturer=s specifications.

Connection Means

For safety and reliability, TVSS units installed at the building service entrance and exterior locations must be directly connected (hard-wired). There are only two connection options available; the unit can have its own leads or terminal lugs can be provided. Since the inductance of the leads affects TVSS performance, their length must be minimized. UL 1449 performance tests are conducted using 15 cm (6 in) leads, therefore lead length should not exceed 15 cm (6 in) for UL rated performance.

Protection Modes

For a grounded wye configuration, protection modes must include L-N (three cases), and L-L (three cases). N-G protection is not necessary if the neutral and ground are solidly connected at the TVSS location, such as at the service entrance or meter. If, however, the neutral and ground are not solidly connected, such as at the service entrance of an outbuilding, then N-G protection must be included.

L-G protection should be avoided because it is not advisable to dump a large amount of current to the ground conductor. Since ground is used as a reference by other systems the large voltage drop that can develop across the conductor (due to 0) can cause problems with other systems. Systems normally considered safe may even be affected if grounds are not properly interconnected. Therefore L-N is the preferred protection mode. (If the ground is earthed at the TVSS location then L-G protection is permissible.)

Also due to the 0 voltage, a large voltage difference may develop between the neutral and ground. To reduce this voltage difference N-G protection is recommended. The performance ratings for the N-G protection circuit should be the same as those for L-N protection. (Of course, if the neutral and ground are solidly connected at the TVSS location, then a N-G suppressor is valueless.)

For a center-tapped delta configuration, protection modes must include L-N (two cases), and L-L (three cases). It is not necessary to include N-G protection if the neutral and ground are solidly connected.

For a corner-grounded delta configuration, if one leg of the delta is solidly grounded, only L-L protection (three cases) is necessary, otherwise L-G protection (three cases) is recommended in addition to L-L.

For an ungrounded delta, an ungrounded wye, or a resistance grounded wye configuration, L-L protection (three cases) and L-G (three cases) are required.

For a single-phase grounded neutral configuration L-L (one case in a 3 wire system) and L-N (1 case in 2 wire systems and 2 cases in 3 wire systems) must be provided. N-G protection is not necessary if the neutral is solidly grounded.

Maximum Surge Current

The maximum surge current rating must be greater than the peak current for the IEEE C62.41 surge environment. A UL 1449 rating assures that the TVSS unit can handle a 10 kA surge, the most severe of the recommended environments.

The maximum surge current rating can also be used as a qualitative measure of TVSS lifetime. Since most surge suppression components deteriorate with use, the additional surge current rating of the TVSS, as compared to the peak current of the relevant IEEE C62.41 surge environment, provides an indication of increased lifetime. In practice, surge suppressors should experience smaller surges than their ratings and so should have a longer life.

Information on maximum surge current capability from UL 1449 performance tests is minimal. For permanently connected TVSS units, a UL 1449 rating guarantees withstanding only two 10 kA surges, which says little about unit lifetime. Therefore additional information must be obtained from the manufacturer. A maximum surge current value greater than the rating for the relevant IEEE surge environment should indicate increased lifetime. IEEE standard waveforms must have been used in the tests so that comparisons can be made between devices and performance can be evaluated for relevant location categories and environments. Maximum surge current, not energy or power, must be used to make this comparison.

Clamping Voltage during Maximum Surge Current

Since the clamping voltage of surge suppressors is current dependent, and increases with increasing current, the maximum clamping voltage of the TVSS will occur with the application of the maximum surge current. This clamping voltage rating is not available from the UL 1449 performance tests, it must be obtained from the manufacturer. IEEE standard waveforms must have been used in the tests so that comparisons can be made between devices and performance can be evaluated for relevant location categories and environments.

Clamping Voltage

The UL 1449 suppressed voltage rating presents only a qualitative evaluation of the TVSS clamping voltage. First, the UL 1449 suppressed voltage rating is based on limiting voltage measurements with a 500 Amp peak current, and second; UL 1449 assigns a suppressed voltage rating to a range of limiting voltages.

The 500 Amp peak test current specified by UL 1449 may be exceeded in actual service. IEEE C62.41, which is based on actual building environments, recommends a minimum peak value of 3,000 Amps for low exposure levels in Category C. Because varistor clamping voltage is dependent on current, the TVSS unit's actual in-service clamping voltage will most likely be greater than that measured at 500 Amps. Fortunately, in assigning the suppressed voltage rating, UL 1449 rounds up, providing a small allowance for the increased clamping voltage at higher peak currents. However, since the rating is assigned by ranges, not percentages, a measured limiting voltage near the upper end of the range will not have as great an allowance as one near the lower end of the range. Quantitative evaluations must not be made when using UL 1449 suppressed voltage ratings, manufacturer's test specifications must be consulted. Be sure IEEE standard waveforms were used for the tests so that reliable interpretations are possible.

UL 1449 uses a 10 kA maximum value for testing TVSS surge current, which is in agreement with the IEEE C62.41 recommended maximum. However, at building exterior locations, C62.41 recommends a maximum surge voltage of 20 kV, while UL 1449 uses only 6 kV. Based on nominal electrical system conductor spacings, 6 kV is the IEEE C62.41 recommended maximum for interior applications. Due to the greater conductor spacings exterior to the building, voltages up to 20 kV can exist. Therefore, in IEEE C62.41 Category C applications, sparkover within a UL 1449 rated TVSS may be a possibility due to the limited UL 1449 test voltage One should check with the manufacturer if voltage breakdown within the TVSS unit due to surge voltages greater than 6 kV is a concern.

Because of the tolerance on components, which could be as high as 10%, actual TVSS clamping performance may differ. Therefore, the clamping voltage should not be specified as exactly 110% of nominal line voltage. 125% of nominal is recommended.

FACILITY INTERIOR TVSS

Circuit Description

A TVSS unit for the facility interior, Categories B and A in IEEE C62.41, may be either parallel or series connected. Inexpensive units will contain just MOVs. Hybrids will contain MOVs as the primary surge suppression component with semiconductor devices as the secondary suppression component.

A TVSS unit for Category B use (subpanels and step-down transformers within the facility) should be treated as a service entrance TVSS unit, with the exception that instead of high energy MOVs they can use medium energy devices (20 mm   disc size < 40 mm). Silicon carbide varistors must not be used at this location.

For reliability, a TVSS unit for Category A use (at outlets within the facility) should contain semiconductor surge suppressors. If they are used as the primary suppression component then they should be a high energy device such as a TransZorb**7**. A lower energy device, such as a diode, can be used as a secondary suppression component if MOVs are the primary suppression component. In this application, MOVs can be of the low energy (10 mm   disc size < 20 mm) type. Silicon carbide varistors must not be used at this location.

Diagnostic indicators, such as LEDs, which show suppressor condition are recommended. As a minimum, a good or failed MOV condition should be indicated. More sophisticated units monitor MOV deterioration and count surges. Redundant protectors provide continuous protection if one should fail. Plug-in modules make replacement of a failed suppression component easy.

Series devices must have overcurrent protection.

Nominal Line Voltage

The rated nominal line voltage of the TVSS unit must be equal to or greater than the voltages for the protected modes (e.g. L-L and L-N). This information is available from the UL label and the manufacturer.

Maximum Continuous Line Current

This rating applies to units which are installed in series with the line and/or neutral conductors. These units should only be used in Category A. The load on the circuit must not exceed the rating on the TVSS.

If the TVSS does not have an internal fuse or circuit breaker then an external one must be provided which does not exceed the current rating of the TVSS.

Maximum Continuous Operating Voltage

The maximum continuous operating voltage must be at least 10% above the nominal line voltage. A UL 1449 rating assures that the unit can operate at 110% of the nominal line voltage. If continuous operation at voltages grater than 110% of the nominal line voltage is required then it is necessary to check the manufacturer's specifications.

Connection Means

Category B units, for installation at subpanels and step-down transformers within the facility, must be treated as service entrance TVSS. These TVSS units must be directly connected (hard-wired).

Cord connected and direct plug-in TVSS units (Category A) are pre-wired with either a polarized plug or integral blades for attaching to an electrical outlet, typically 120 Volts. For proper TVSS operation polarity must be maintained. If the TVSS unit is plugged into an extension cord, the cord must be grounded and have conductors of sufficient size to handle the TVSS rated current load; a minimum size of 14 AWG for 15 Amp units and 12 AWG for 20 Amp units.

Protection Modes

Protection modes for category B units (ones installed at subpanels and step-down transformers) are determined as for service entrance TVSS units, with the exception that N-G protection is now required since the neutral and ground are not solidly connected.

L-G protection should be avoided because it is not advisable to dump a large amount of current to the ground conductor. L-N protection is preferred over L-G.

N-G protection is recommended to reduce the voltage difference which may develop between the neutral and ground during a surge. The performance ratings for the N-G protection circuit should be the same as those for L-N protection.

Category A units (cord connected and direct plug-in) must have L-N and N-G protection. L-G protection is to be avoided.

Maximum Surge Current

The maximum surge current rating must be greater than the peak current for the IEEE C62.41 surge environment. A UL 1449 rating assures that the TVSS unit can handle a 10 kA surge, the most severe of all recommended environments.

The maximum surge current rating can also be used as a qualitative measure of TVSS lifetime. Since most surge suppression components deteriorate with use, the additional surge current rating of the TVSS, as compared to the peak current of the relevant IEEE C62.41 surge environment, provides an indication of increased lifetime. In practice, surge suppression components should experience smaller surges than their ratings and so should have a longer life.

Information on maximum surge current capability from UL 1449 performance tests is minimal. For permanently connected TVSS units (category B), a UL 1449 rating guarantees withstanding only two 10 kA surges, which says little about unit lifetime. Therefore additional information must be obtained from the manufacturer. A maximum surge current value greater than the rating for the relevant IEEE surge environment should indicate increased lifetime. IEEE standard waveforms must have been used in the tests so that comparisons can be made between devices and performance can be evaluated for relevant location categories and environments. Maximum surge current, not energy or power, must be used to make this comparison.

For categories B and A, IEEE C62.41 recommends a 100 kHz Ring Wave performance test, which is not used by UL 1449. This test can supply additional information concerning multiple triggering of the TVSS, because of the periodicity of this waveform. An independent testing agency or the manufacturer should be contacted for this information.

Clamping Voltage during Maximum Surge Current

Since the clamping voltage of surge suppressors is current dependent, and increases with increasing current, the maximum clamping voltage of the TVSS will occur with the application of the maximum surge current This clamping voltage rating is not available from the UL 1449 performance tests, it must be obtained from the manufacturer. IEEE standard waveforms must have been used in the tests so that comparisons can be made between devices and performance can be evaluated for relevant location categories and environments.

For facility interior TVSS units, IEEE C62.41 recommends a 100 kHz Ring Wave performance test, in addition to the pulse waveforms. This test can supply additional information concerning multiple triggering of the TVSS, because of the periodicity of this waveform. An independent testing agency or the manufacturer should be contacted for this information.

Clamping Voltage

The concern that the UL 1449 suppressed voltage rating presents only a qualitative evaluation of the TVSS clamping voltage is also true for facility interior TVSS units. (In the case of an interior TVSS, IEEE C62.41 recommends a minimum peak test value of 1,000 Amps, this for low exposure level in Category B, while UL 1449 tests at 500 Amps peak.) Therefore only qualitative evaluations can be made when using UL 1449 suppressed voltage ratings. For quantitative comparisons, manufacturer's test specifications must be consulted. Make sure IEEE standard waveforms were used for the tests so that reliable comparisons are possible.

IEEE C62.41 recommends only the 100 kHz Ring Wave test for Category A, not the Combination Wave, which UL 1449 uses. Although these waveforms are not equivalent, a UL 1449 rating using only the Combination Wave gives some level of confidence that the TVSS can perform as a TVSS. Additional information on TVSS performance to a ring wave should be obtained. In striving to pass the UL 1449 test, a manufacturer may be forced to use a higher energy suppression component, with less accurate clamping voltage performance, in order to pass the extreme 10 kA test. Thus degrading the TVSS unit's performance in the category A environment, where a 200 Amp peak Ring Wave is the severest pulse. An independent testing agency or the manufacturer should be contacted for this information.

A clamping voltage of 125% of nominal line voltage is recommended due to the tolerance on components, which could be as high as 10%.

WAVESHAPE TRACKING AND ENVELOPE CLAMPING

In envelope clamping the maximum value of the instantaneous voltage is limited to a fixed value, providing an envelope of protection.

Waveshape tracking follows the waveshape using a sort of moving envelope of protection. It attempts to limit the voltage excursion to a fixed value, in contrast to simply limiting the voltage to a fixed value. For example if a positive impulse were to occur at the voltage minimum the waveshape tracking device would trigger before the envelope tracking device, further limiting the voltage excursion.

RESPONSE TIME

The response time (or turn-on time) listed in most manufacturer's specifications is not an important consideration in TVSS selection. The fastest rise time for an IEEE C62.41 standard waveform is 0.5 s (or 500 ns). This time is more than 10 times slower than the turn-on time for a typical suppression component. Compared to 500 ns there is no significant difference between a 10 ns, 5 ns, 1 ns or instantaneous response time. If the device was tested using any of the IEEE C62.41 standard waveforms, and performed well, then actual response time is immaterial.

ENERGY AND POWER

If energy and power ratings are not interpreted correctly they can be very misleading. Power is voltage times current, 0, and is given in Watts. Energy is the integral of power over time, 0, and is given in Joules.

Device failure is directly related to energy absorption. Energy ratings can be easily calculated for individual suppressor components, but not for complex TVSS units. Additionally there are no standard guidelines on how to determine ratings. For example, does one simply add up the energy capabilities of all the components? But not every component will be absorbing energy at the same time (e.g. L-L and L-N surges will trigger different devices).

Because of the ambiguity in determining energy and power ratings, these specifications should not be used in evaluating TVSS performance.

OTHER CONSIDERATIONS

INSTALLATION

Installation of hard-wired TVSS units can generally be done with terminals, either plug-in or screw type. If a screw terminal is unavailable, connections to ground can typically be accomplished using self-tapping screws and lock washers. TVSS lead lengths must be kept to a minimum. The size of any necessary connecting wires is somewhat installation dependent, but can be 12 gauge copper in most cases. Ground must be verified to insure that it is truly connected to the building electrical power ground.

Cord connected and direct plug-in TVSS units are pre-wired with either a polarized plug or integral blades for attaching to an electrical outlet, typically 120 Volts. Polarity must be maintained. The outlet should be checked to verify that line, neutral, and ground are each present, and on the proper terminals. If the TVSS unit is plugged into an extension cord, the cord must be grounded and have conductors of sufficient size to handle the TVSS rated current load; a minimum size of 14 AWG for 15 Amp units and 12 AWG for 20 Amp units.

In consideration of a TVSS failure, it should be installed in a fail-safe manner, which also provides indication upon failure. The TVSS must be installed on the load side of a protective device, such as a circuit breaker or fuse, so that the protective device will trip if the TVSS fails short. The blown fuse or tripped breaker will provide indication of the failure. Note that UL 1449 approval for surge suppressors does not apply to devices that are installed on the line side of the facility main breaker.

Proper grounding of the facility=s subsystems (e.g. electrical, telecommunications, lightning) is as important for preventing damage to electrical and electronic devices as the TVSS unit. Exterior grounds are used on commercial power distribution systems for lightning protection and preventing shock hazards at the point of entry into a facility. The exterior ground may be isolated from or extend to the facility, depending upon the type of power system. Facility interior grounds prevent shock hazards, provide signal referencing, reduce transient currents on internal power distribution, and protect life support systems and equipment used for internal signal distribution.

Bonding is the process of ensuring that electrical connections between components of a grounding system have very low impedance (on the order of milliohms). Direct connection of components without the use of straps or wires is preferable. Clean metal-to-metal contact between components is required, and may be achieved by order of preference; welding, soldering, bolting, and riveting. Welding and soldering require little or no maintenance but reduce the portability of system components. (Soldering should not be used on connections where direct lightning stroke currents are possible; the large currents can melt the solder and break the connection.)

MIL-HDBK-419[4] is an excellent reference for grounding and bonding information.

SUPPRESSOR COORDINATION

The concept of coordination of TVSS units is based on the application of a unit at each of the three facility locations or categories of IEEE C62.41. A device with high energy handling capability is installed at the service entrance. It is expected to divert most of the surge current at that point. The second device, which is installed down line within the premises, can then have a lower energy handling capability. The benefit from this approach is that it allows a single device at the service entrance to perform the high-energy duty, and relies on smaller devices to perform local suppression. This prevents the flow of large surge currents in the branch circuits of the installation.

Some electrical utilities recommend a service entrance suppressor that is capable of withstanding the 240 Volts overvoltage that can occur on the 120 Volts branches when the neutral is lost. If low voltage suppressors are used down stream, this may result in a situation in which the low voltage suppressor acts first, in most cases an undesirable situation.

The facility should be considered as a whole when selecting TVSS units. IEEE C62.41 outlines a scheme for dividing the facility into sections which can then be addressed independently.

CONCLUSION

By considering the location in the facility of a TVSS unit, the probable transient environment, and evaluating TVSS ratings based on published standards, a TVSS unit can be selected with reasonable confidence that it will perform acceptably.

For a detailed and theoretical treatment of the subject of transient surge suppression, Standler[5] is an excellent reference.

REFERENCES

1. IEEE C62.41-1991, *IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits*.

2. NEMA LS1, *Low Voltage Surge Protective Devices*.

3. UL 1449, *Transient Voltage Surge Suppressors*.

4. Department of Defense, *Grounding, Bonding, and Shielding for Electronic Equipments and Facilities*, Military Handbook 419A, Department of Defense, Washington, DC, December 1987.

5. R. B. Standler, *Protection of Electronic Circuits from Overvoltages*, John Wiley and Sons Inc., New York, 1989.

AUTHOR'S ADDRESS:

U.S. ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORIES
ATTN: CECER-FL-P (M. McInerney)
P.O. BOX 9005
CHAMPAIGN IL 61826-9005

U.S. ARMY CENTER FOR PUBLIC WORKS
ATTN: CECPW-EE (T. Luu)
BUILDING 1929
7701 TELEGRAPH ROAD
ALEXANDRIA VA 22315-3862